An accurate analog delay circuit

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There are several ways to introduce an analog delay into a signal channel. If you have enough room in your product, an appropriate length of coax cable can be introduced. Inductor-capacitor delay lines can be purchased. My preference is to create the delay with active circuitry, which doesn't take up much space and can be designed to precisely implement whatever delay time is needed. This approach could even be made voltage-adjustable since there's only a single resistor and capacitor controlling the delay line.

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The Laplace transform of an ideal delay is exponential:

$$\frac{V_o}{V_i} = \exp(-\tau * s)$$

(whereτ is the desired delay), which requires an infinite number of poles and zeroes to implement. Because the ideal form can't be implemented (practically), we need to use an approximation.

An accurate, simple approximation to the ideal can be achieved by using a technique known as Padé approximation. The first-order Padé approximation to an ideal delay has the following form:

$$\frac{V_o}{V_i} = \frac{1 - \tau s / 2}{1 + \tau s / 2}$$

(where τ is the desired delay).

The circuit in Figure 1 has the following transfer function: which has the same form as the first order Padé

approximation, with the R*C time constant equaling half the desired delay time.

$$\frac{V_o}{V_i} = \frac{1 - R*C*s}{1 + R*C*s}$$

The circuit was built with 1% resistors and a capacitor with a value measured at 63 pF. This combined with a resistor value of 95.3Ohms gives an R*C value of 5.94 ns. This R*C time constant corresponds to an overall delay time of 11.9 ns (τ is 2*R*C).

Measuring the delay time of this circuit with a 5-ns rise-time pulse gave a delay of 12.2 ns, which is a pleasingly accurate result. The accuracy for this short of a delay time can be attributed both to the success of the Padé technique and to the wide bandwidth of the CLC428 op amp used in the circuit. Using a slower amplifier will result in a less accurate delay.

Accurate delay values are easily accomplished using only a first-order approximation. The circuit works effectively, even for short delay times, if a fast enough amplifier is used.

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